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Caveats for the CMB Level 2 Product in the GPM V04 Public Release

The Combined Radar-Radiometer Algorithm (CMB) L2 V04 product includes precipitation estimates over the broader, NS (Ku+GMI) swath as well as estimates over the narrower, MS (Ku+Ka+GMI) swath. The input of the CMB L2 algorithm is derived from DPR L2 and GMI L1 products. In particular, the CMB L2 algorithm depends upon inputs from the DPR L2 Preparation Module, Classification Module, Surface Reference Technique Module, and the Vertical Structure Module. From GMI L1, the CMB L2 algorithm utilizes the intercalibrated brightness temperature observations.

During the early GPM mission (prior to June 2014) many tests and modifications of the DPR performance were carried out, and these can have an impact on not only DPR products but also the CMB L2 estimates that depend on them. Therefore, CMB L2 precipitation estimates from the early mission should be used with caution. A listing of the orbits impacted by these tests and modifications can be obtained from the GPM Radar Team.

Mainlobe and sidelobe clutter contamination of DPR reflectivities has been reduced using radar beam reshaping and statistical corrections. The combination of these applications has reduced clutter successfully over most surfaces, but there are still “exceptional” regions where clutter signatures are still evident. Also, ice-covered land surfaces produce Ku-band radar surface cross-sections at nadir view that sometime exceed the upper limit of the radar receiver range. Estimates of Ku-band path-integrated attenuation from the Surface Reference Technique Module are possibly biased in these regions. Since radar reflectivities and path-integrated attenuations are utilized by the CMB L2 algorithm, precipitation estimates in these “exceptional” regions should be used with caution.

The current CMB L2 algorithm uses the Ku-band radar reflectivities from the Preparation Module to detect either liquid- or ice-phase precipitation. The lowest detectable reflectivity for DPR at Ku band is ~13 dBZ, and so light snow or very light rainfall may not be detected and quantified by the algorithm.

In addition to the impact of input data from DPR L2, there are uncertainties due to the current limitations of the CMB L2 algorithm’s physical models and other assumptions that will also have an impact on precipitation estimates. In particular, the physical models for scattering by ice-phase and mixed-phase precipitation particles are simplified. These scattering models in the CMB algorithm will be improved for the purpose of generating precipitation estimates in future product releases. Also, the effects of radar footprint non-uniform beamfilling and multiple scattering of transmitted power have been addressed in CMB L2, but are not yet generalized and have not been analyzed in detail. Multiple scattering primarily affects Ka-band reflectivities, and sometimes eliminates earth surface reflection, in regions of strong radar attenuation, while footprint non-uniform beamfilling impacts the interpretation of both Ku- and Ka-band radar data. As a consequence, NS and MS swath precipitation estimates associated with intense convection, in particular, should be treated with caution. Finally, the assumed *a priori* statistics of precipitation particle size distributions can have an influence on estimated precipitation. As particle size distribution data are collected during the mission, more appropriate assumptions regarding the *a priori* statistics of particle sizes will be specified in the algorithm. At this stage of the mission, however, insufficient data on particle size distributions have been collected for the purpose of updating *a priori* statistics, and so biases in estimated precipitation and underlying particle size distributions can occur.

It should also be noted that both precipitation estimates and retrievals of environmental parameters from CMB L2 have not yet been comprehensively validated using ground observations. Such a validation effort has begun and will continue after the V04 release of the CMB L2 product. Therefore, it is very important that users of the public release product keep in contact with the CMB Team for updates on the validation of precipitation estimates and any reprocessing's of the CMB L2 algorithm product.

Preliminary validation of the V04 CMB L2 product has revealed good consistency between estimated surface precipitation rate and raingage-calibrated radar, with correlations greater than 0.80 between 0.5 degree-resolution instantaneous estimates of surface precipitation rate and gage-calibrated radar (Multi-Radar Multi-Sensor [MRMS] product) over the continental US and coastal waters. However, regional biases are seen, with some positive biases relative to gage-calibrated radar in convective regimes over land, and smaller negative biases over coastal waters. Zonal mean precipitation rates agree well with zonal mean precipitation rates from the Global Precipitation Climatology Project (GPCP) product within the 40 ^{o}S to 40 ^{o}N latitude band. Estimated zonal means at higher latitudes are underestimated relative to GPCP, due in part to the limited sensitivity of the DPR radar to light snow and drizzle. Although agreement of zonal means between 40 ^{o}S – 40 ^{o}N is noted, regional positive biases over land and compensating weaker negative biases over ocean relative to GPCP are evident, and these biases are consistent with the bias patterns inferred from the MRMS product over the US and coastal waters.

There could potentially be significant changes in the CMB L2 rain rate products in the transition from V04 to V05 due to expected changes in the DPR radar calibration as well as adjustments and improvements of the CMB algorithm. Again, the users of the V04 public release product should keep in contact with the CMB Team for information regarding these changes.

CMB L2 V03 to V04 Changes

Many updates have been made to the CMB L2 algorithm in the transition from V03 to V04, and the significant updates are summarized here. It may be noted at the outset, however, that the basic algorithm mechanics (i.e., estimation methodology) and output file structure have not changed. The estimation method filters ensembles of DPR Ku reflectivity-consistent precipitation profiles using the DPR Ka reflectivities, path integrated attenuations at Ku and Ka bands, and GMI radiances. The filtered profile ensembles are consistent with all of the observations and their uncertainties, and the mean of the filtered ensemble gives the best estimate of the precipitation profile.

In the CMB V03 and V04 algorithms, input data are passed from the DPR L2 and GMI L1C algorithms. However, to obtain better responsiveness of precipitation profile estimates to the GMI data in V04, input radiances are first resolution-enhanced to approximately the spatial resolution of the DPR resolution (~5 km). This enhancement is accomplished, at each channel frequency and polarization, using a statistically derived filter that predicts the DPR-resolution radiance from a weighted average of native-resolution GMI radiances in a small neighborhood of the observation to be enhanced. Filter weights are derived from regressions on synthetic radiance data, and the degree of enhancement is traded against noise amplification, with an optimal balance between enhancement and noise determined by cross-validation. Use of the resolution-enhanced data leads to a greater responsiveness of precipitation estimates to the GMI radiometer data, and a better fitting of those data. Moreover, data from all thirteen of the GMI channels are utilized in the V04 CMB algorithm, whereas data from only seven channels were used in the V03 algorithm.

In V03, the impact of multiple scattering on simulated reflectivities was crudely represented by typical reflectivity corrections (relative to single-scattering calculations) as functions of bulk scattering optical depth. This simple correction of reflectivities is replaced in V04 by the full simulation of multiple-scattering affected reflectivities using the 1D time-dependent radiative transfer model of Hogan and Battaglia (2008). This model is fully invoked only in situations where single- and multiple-scattering reflectivity simulations based upon the ensemble-mean, Ku-consistent precipitation profile are significantly different, in which case the multiple-scattering model is applied to all ensemble member profiles to simulate the Ka reflectivities. The impact of multiple scattering on Ku reflectivities is generally much smaller than at Ka band and is not considered in V04.

The general parameterization of the effects of radar footprint non-uniform beamfilling by precipitation is the same in CMB V03 to V04; however, the impact of non-uniform beamfilling on simulations of average path-integrated attenuation at the earth's surface is now properly represented in this parameterization in V04.

This allows more consistent comparisons of simulated and surface reference technique (SRT) derived path-integrated attenuations in the algorithm.

Further, the use of individual SRT-based estimates of path-integrated attenuation at Ka band in V03 has been replaced by differential Ka-Ku path-integrated attenuation in the MS (Ku+Ka+GMI) mode of the CMB V04 algorithm. The precipitation-free differential Ka-Ku path-integrated attenuation reference is much more stable than the Ka-band reference, particularly over land surfaces, and this leads to less uncertainty in SRT-derived, differential Ka-Ku path-integrated attenuation estimates in precipitation regions. The SRT differential path-integrated attenuation is used to directly filter the precipitation profile ensembles, rather than inferring the individual Ku and Ka path-integrated attenuations from the differential path-integrated attenuation, and then filtering with those individual path-integrated attenuations.

The expected uncertainties of forward model simulations (relative to observations) prescribed in the ensemble filter kernel are changed from 1.4 dB to 3 dB for Ka-band reflectivities and from 5 ^{o}K to 6.1 ^{o}K for GMI radiances at frequencies above 37 GHz, going from V03 to V04. Expected uncertainties of path-integrated attenuations are maintained at 4 dB in the filter, and uncertainties of GMI radiances at frequencies up to 37 GHz are maintained at 5 ^{o}K.

Hogan, R. J., and A. Battaglia, 2008: Fast lidar and radar multiple-scattering models. Part II: Wide-angle scattering using the time-dependent two-stream approximation. *J. Atmos. Sci.*, **65**, 3636–3651.